Parametric Analysis of Particle CSP System Performance and Cost to Intrinsic Particle Properties and Operating Conditions

ASME Energy and Sustainability July 16, 2019

Session 3-11: Integrated CSP Systems Two (ES2019-3893)

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SAND2019-8280C

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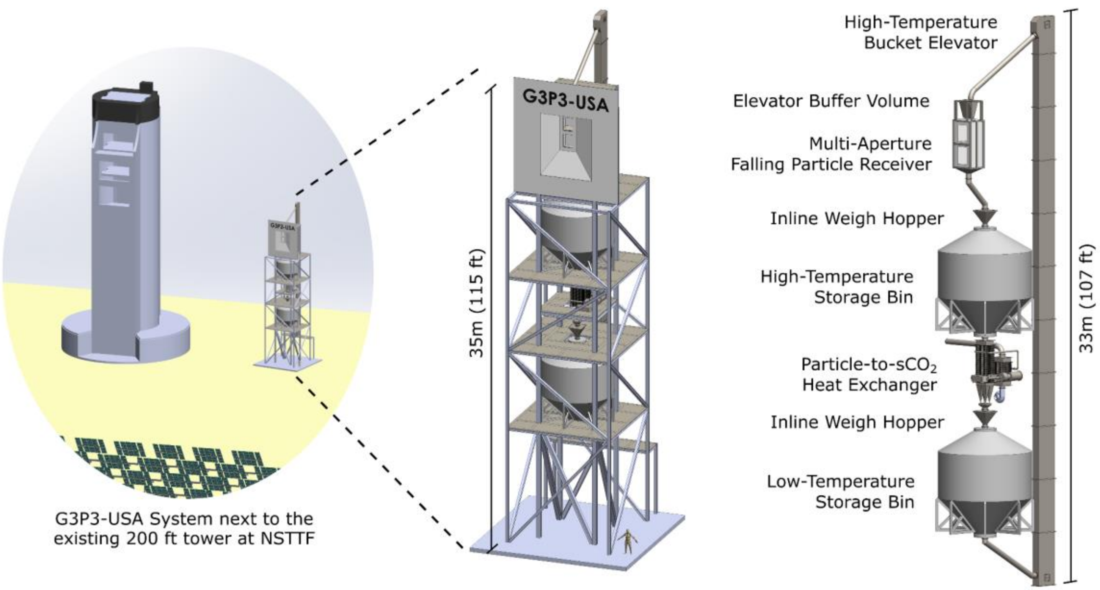
Particle heat transfer media is being considered for next generation CSP plants

Advantages:

- Stability over wide temperature range (sub-zero to >1000 °C)
- Direct absorption of concentrated solar (no flux limitation)
- Inert, noncorrosive, low cost material
- Direct storage of heat transfer media

Challenges:

- Low heat transfer coefficient when indirectly heated or cooled (heat exchanger cost)
- Particle loss, attrition, erosion is a potential concern
- Low temperature rise, thermal efficiency for a single pass falling particle receiver



Particle CSP needs a dedicated tool for cost and performance analysis

Particle system technoeconomic analysis has previously used SAM's generic model

- Component cost and performance can only be modeled at a high level (inputs)
- Influence of operating conditions on component sizing and cost is not easily captured
- Propagating particle properties into component performance and cost is not possible

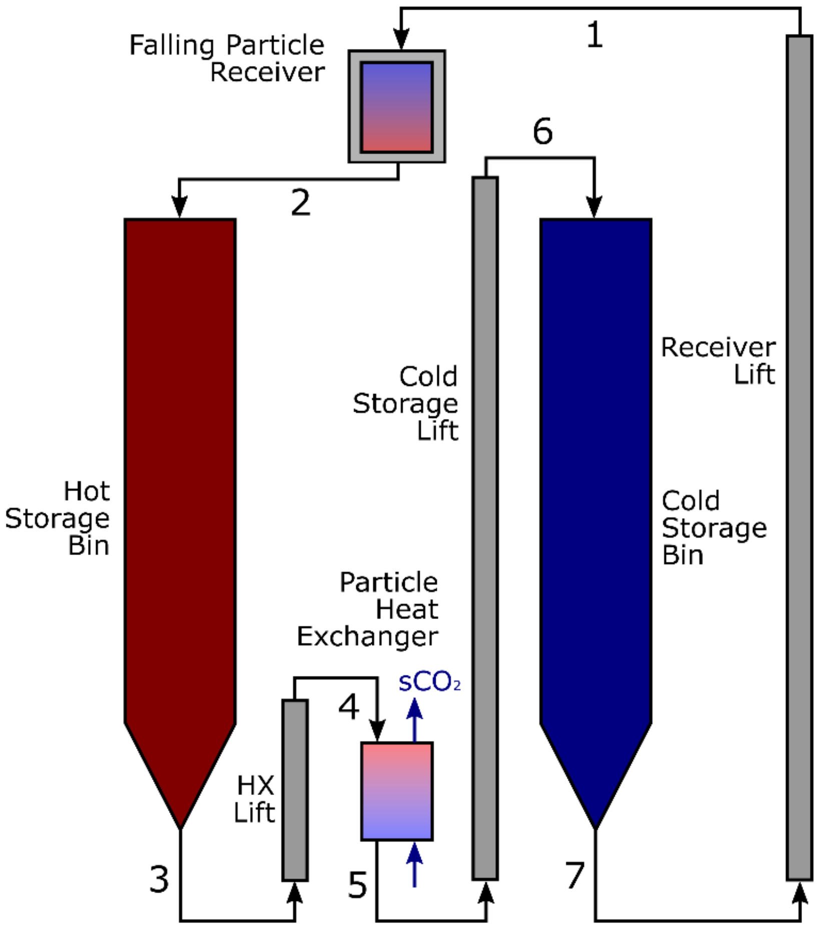
New Approach:

Detailed component submodels are solved with fidelity that can propagate component design information directly into the plant performance and economics

Questions to be answered:

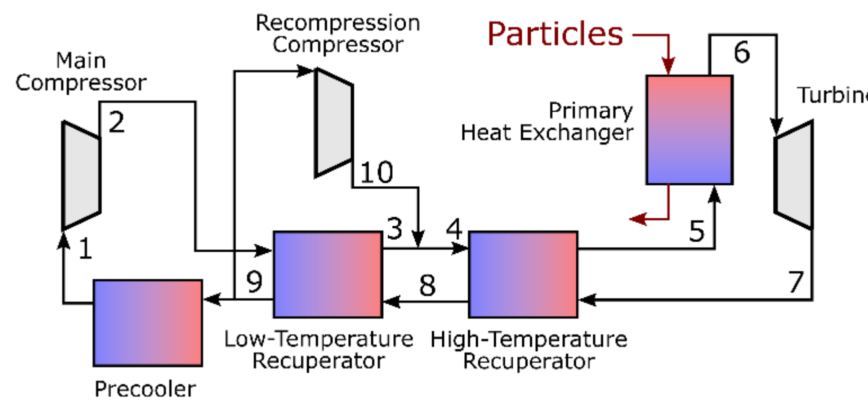
- What is the optimal solar multiple and storage size for a baseload plant?
- What is the optimal hot storage temperature and heat exchanger approach temperature?
- When does particle loss become an economic concern?
- What is the allowable tradeoff between particle absorptivity and cost?
- What is the optimal sCO_2 cycle configuration?

System Configuration and Modeling Approach



Baseline Particle System Configuration

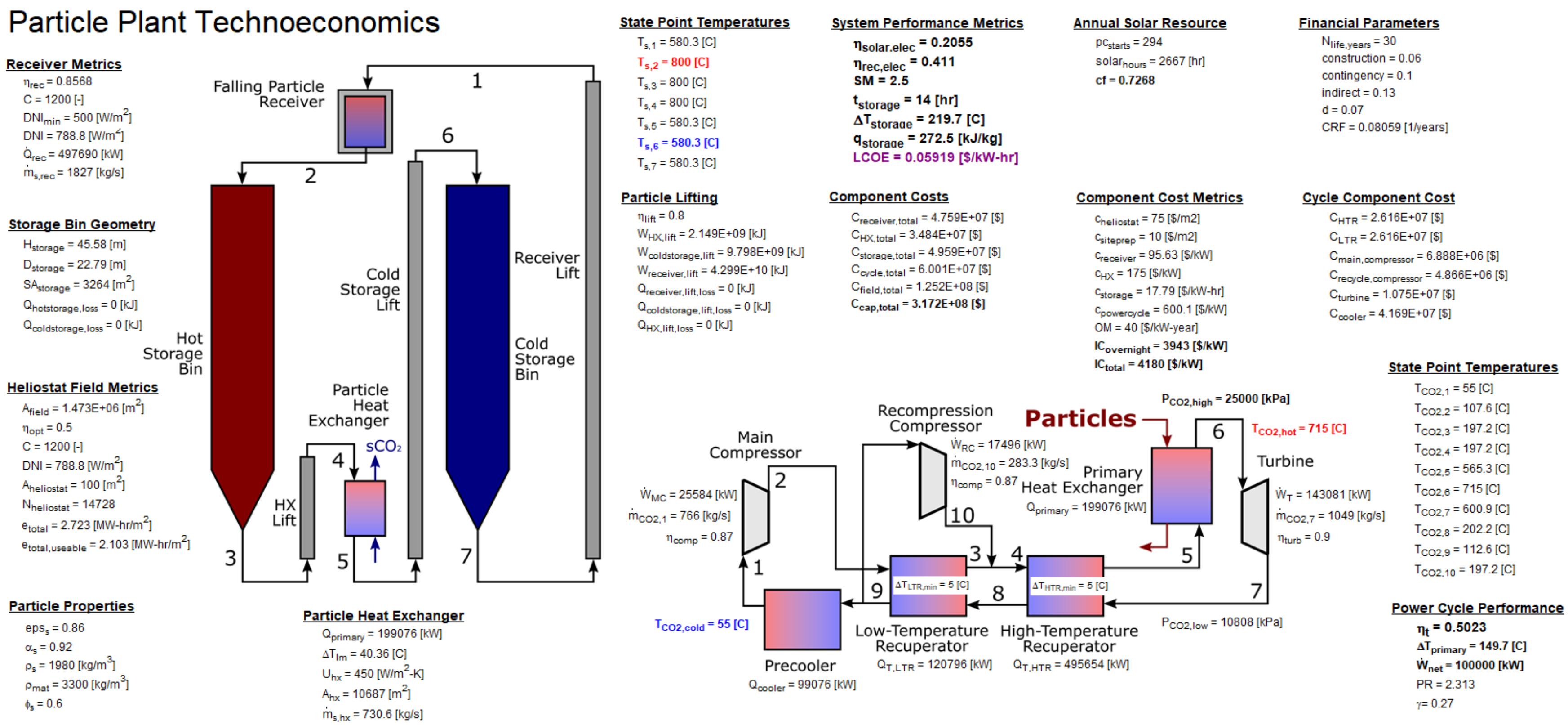
- 100 MWe baseload plant
- Located in Dagget, CA
- Receiver is free falling particle receiver
- Hot and cold storage bins at located at ground level
- Heat exchanger is moving packed bed in counterflow
- sCO_2 cycle configuration is RCBC
- Particle lifting with skip hoist



Components are modeled using 1-D or 0-D and sized during the simulation based on operating conditions and performance

- 1-D: Receiver, Primary Heat Exchanger, sCO_2 Recuperators
- 0-D: Storage Bins, Lifts, Turbomachinery

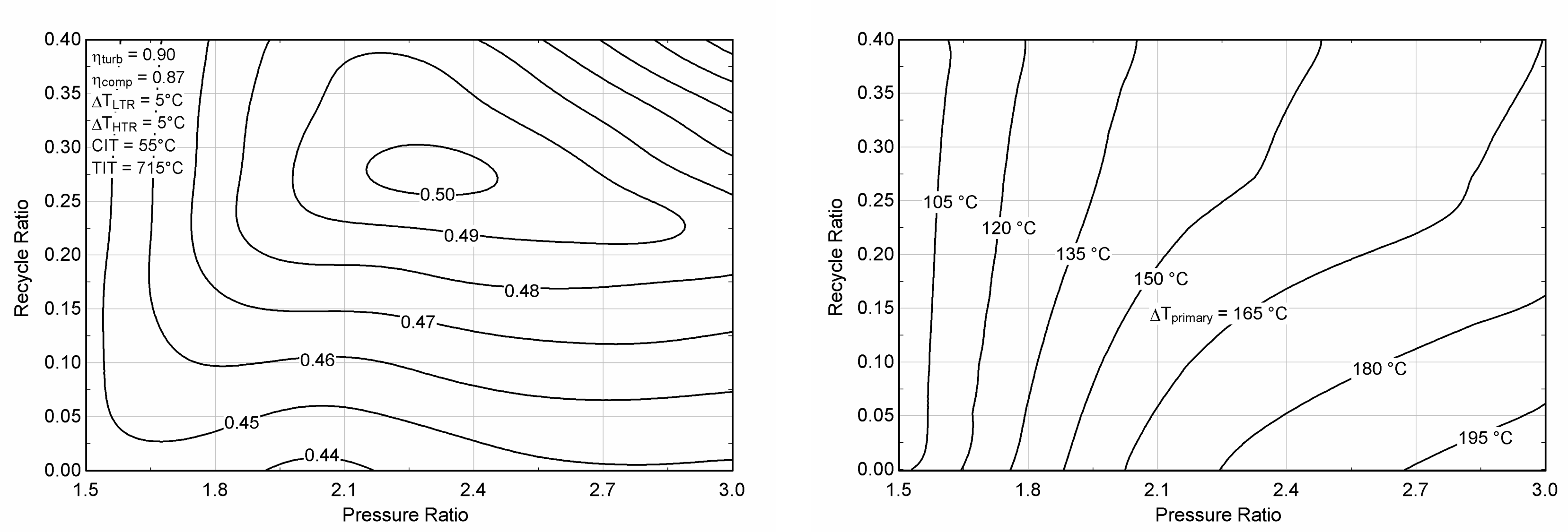
Gen3 Particle System Technoeconomic Tool



Model developed in Engineering Equation Solver (EES) to easily couple to sCO_2 properties for power cycle analysis

Dispatched against hourly TMY data using a procedure to model annual production

sCO_2 Power Cycle Operating Conditions

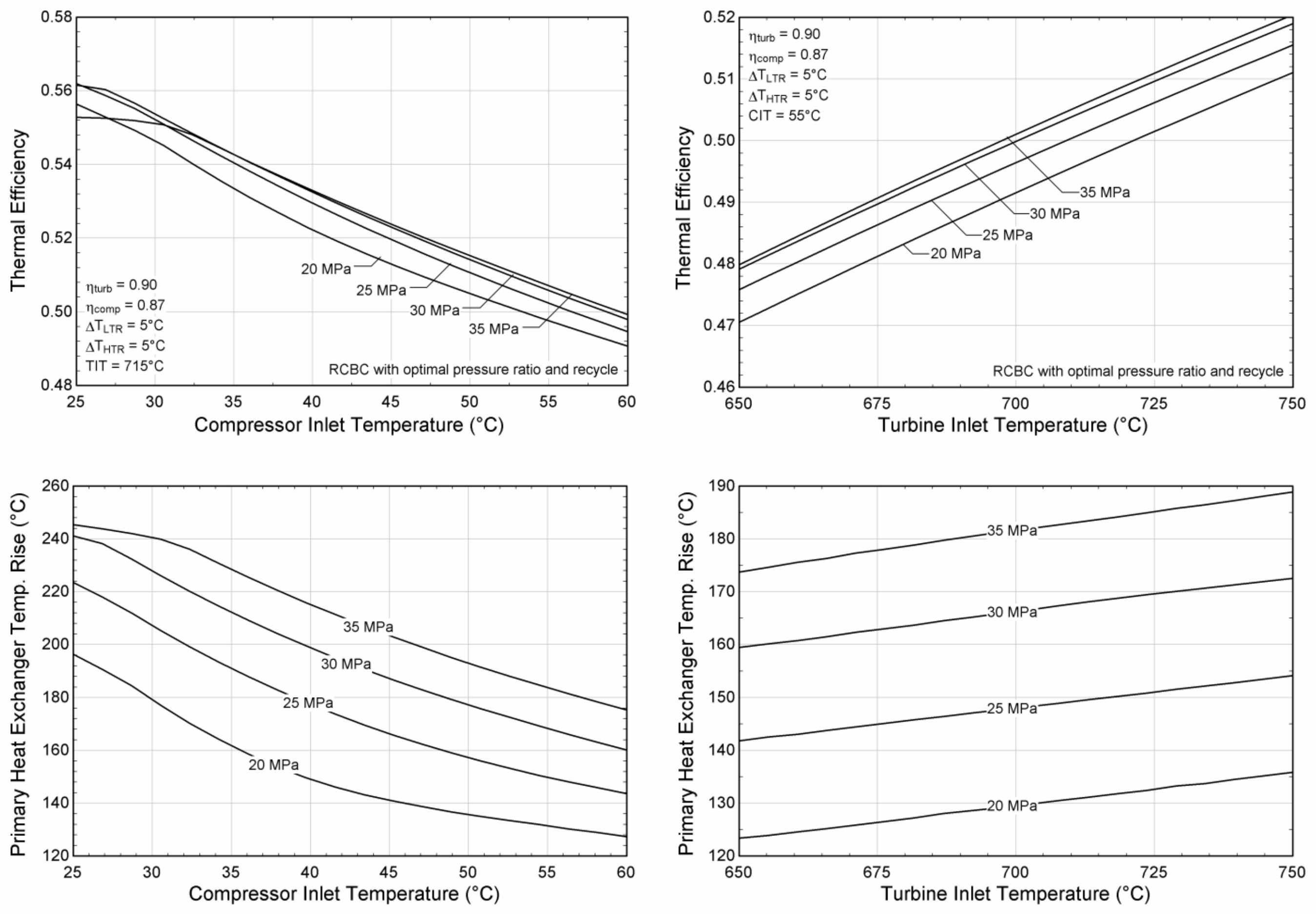


Power cycle operating conditions determine primary heat exchanger temperature rise (energy storage) and thermal to electric conversion efficiency

Optimizing thermal efficiency (50.2%) results in primary heat exchanger temperature rise of 149.7 °C

Increasing pressure ratio can increase primary power cycle temperature rise at reduced thermal efficiency

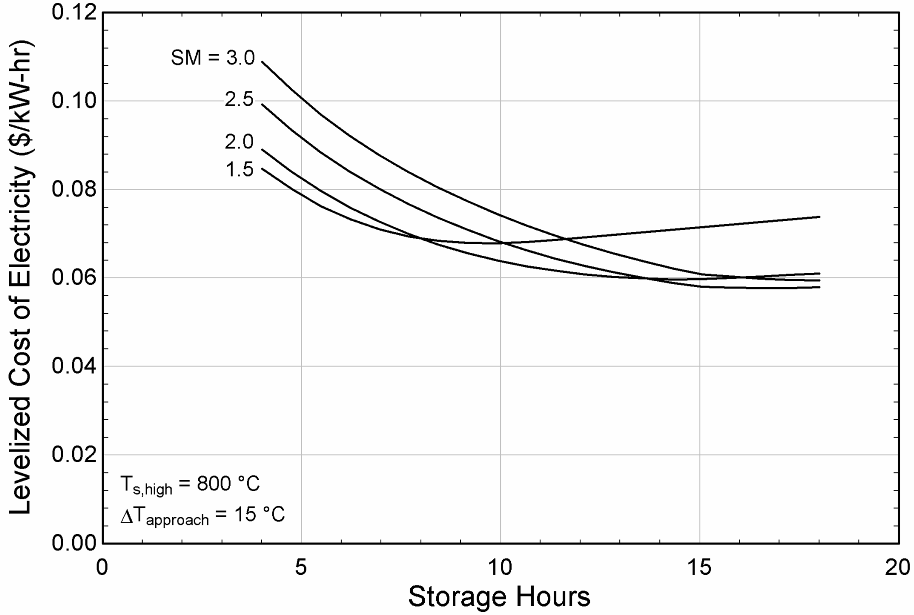
Sensitivity of Efficiency and Temperature Rise to sCO_2 Cycle Pressure and Temperature



Reducing compressor inlet temperature results in large improvements in thermal efficiency and primary heat exchanger temperature rise

Thermal efficiency and temperature rise shows significantly less sensitivity to turbine inlet temperature

Sensitivity to Solar Multiple and Storage



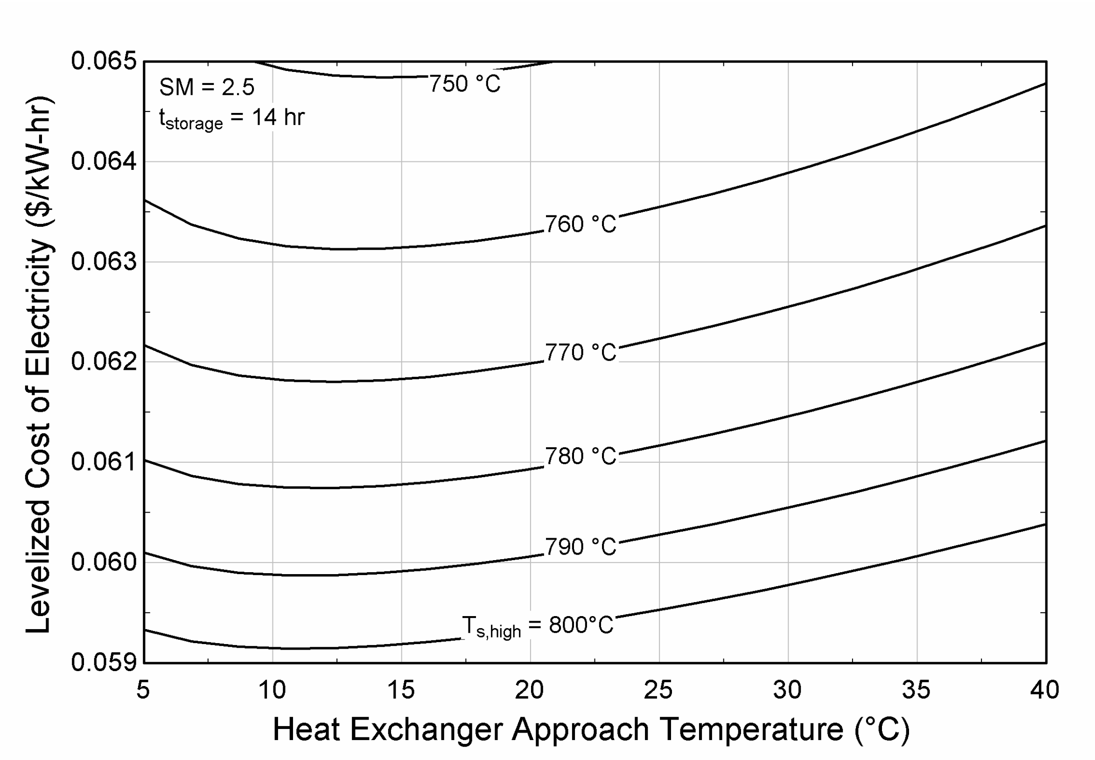
Metric	Target [5]	Baseline
Receiver Cost ($ kW_t^{-1})	150	95.63
Storage Cost ($ $kWt^{-1}hr^{1}$)	15	17.79
Heat Exchanger Cost ($ kW_t^{-1})	150	175.00
Power Cycle Cost ($ kW_e^{-1})	600	600.00
Receiver Efficiency	90%	85.7%
Power Cycle Efficiency	55%	50.2%
Capacity Factor	69%	71%
LCOE ($ kWe^{-1} hr^{1})	0.06	0.0592

LCOE minimizes at solar multiple of ~2.5 and >14 hours of storage

Predicted cost distribution varies from DOE targets, but meets $0.06/$kW_e$-hr goal

- Low cost of falling particle receiver allows for heat exchanger and storage to exceed targets
- Receiver thermal efficiencies below 90% can still achieve cost targets

Selection of Hot and Cold Storage Temperatures

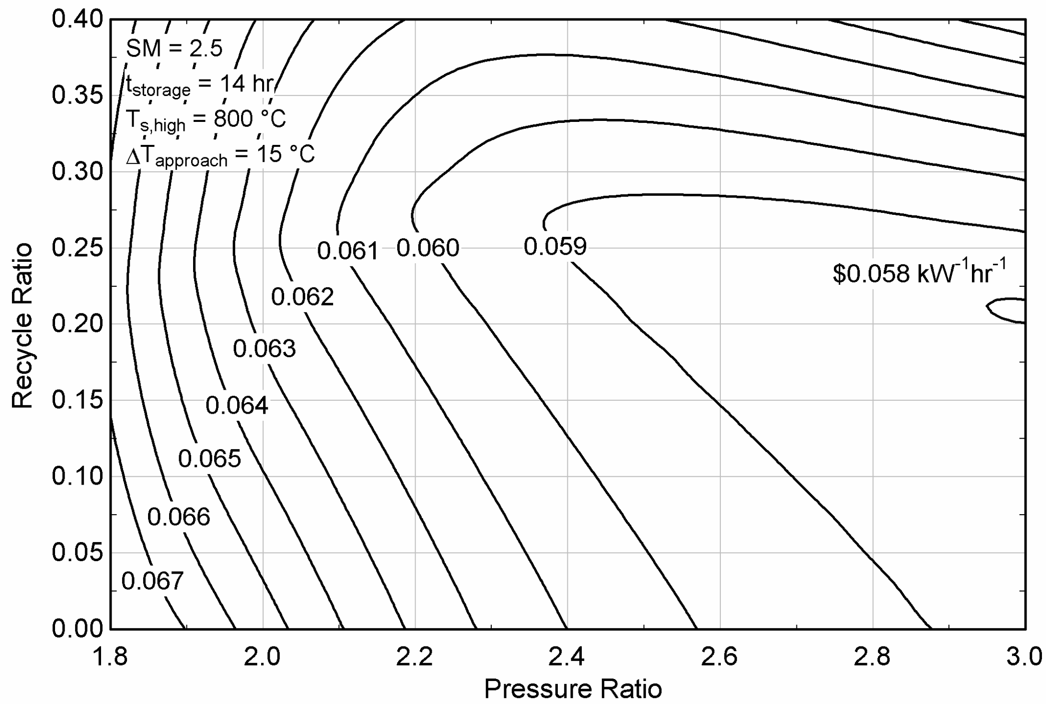


Increasing hot storage temperature reduces receiver thermal efficiency and heat exchanger size, but increases heat exchanger cost per surface area

Reducing heat exchanger approach temperature reduces storage inventory, but increases heat exchanger size

Approach temperature optimizes between 10-15 °C and LCOE reduces with increased hot storage temperature

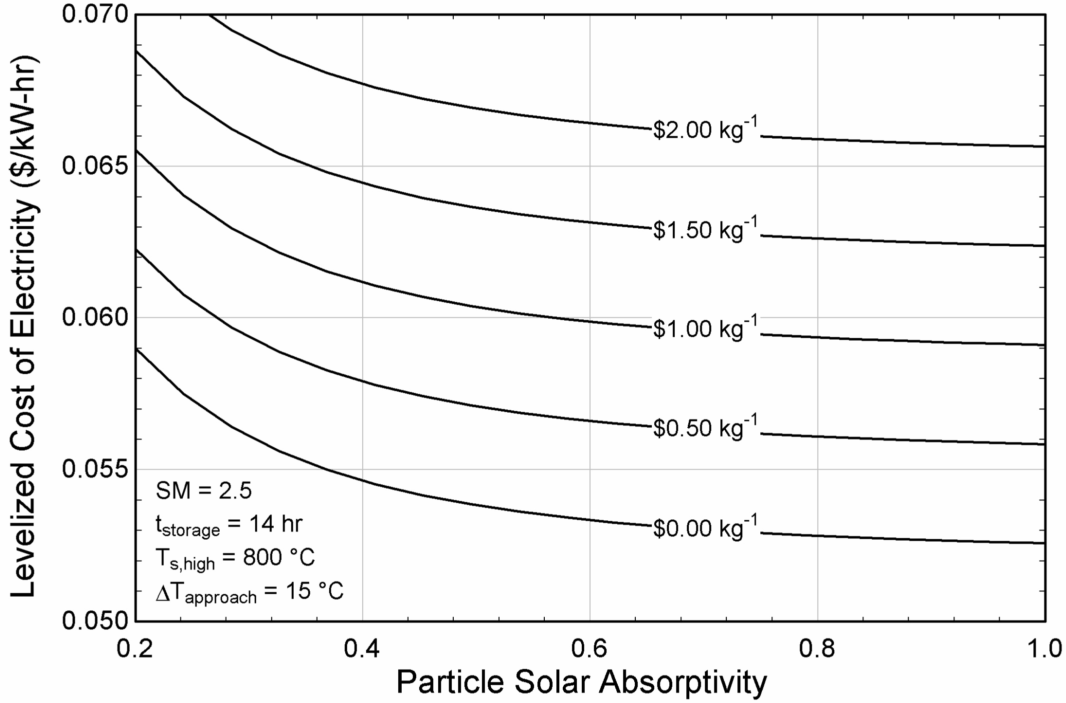
Influence of Power Cycle Operating Conditions on LCOE



LCOE minimizes at RCBC operating conditions other than optimal efficiency

Increasing pressure ratio increases the primary heat exchanger temperature rise and the fraction of the heat exchanger constructed from high-nickel alloys

Particle Cost and Absorptivity

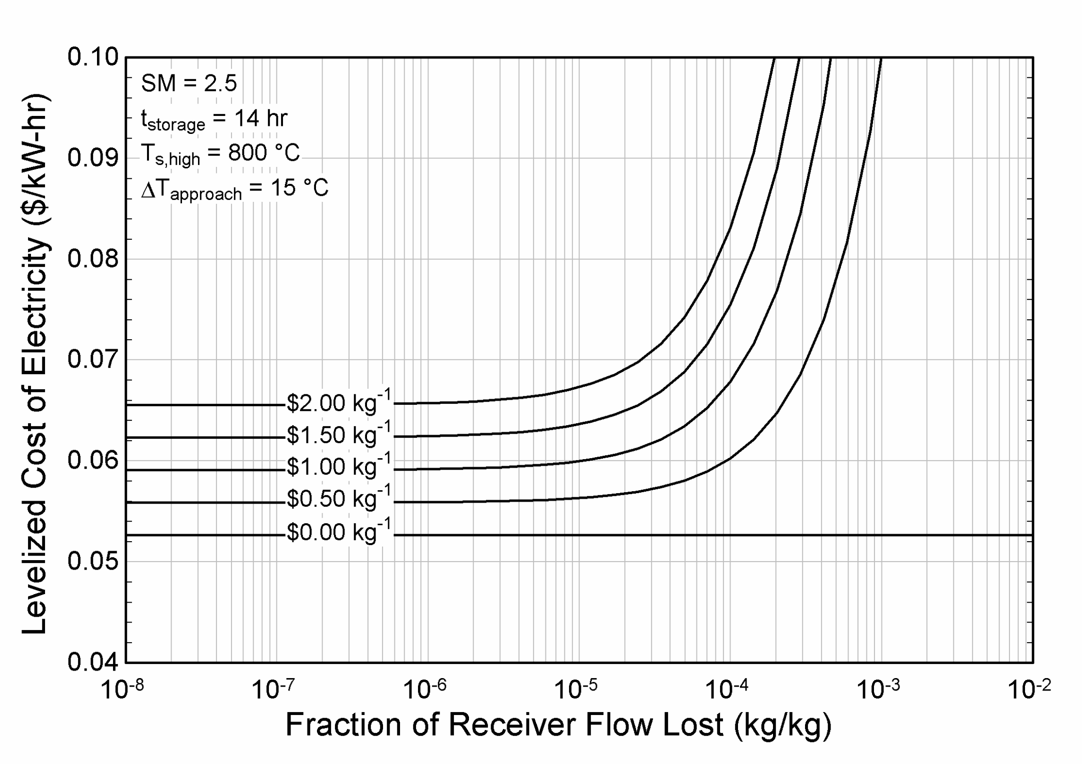


LCOE cost targets can not be achieved with particle cost exceeding $1.00/kg

Low cost particles can still achieve cost targets at reduced solar absorptivity

- Particle selection has many additional consideration (flowability, cohesion, durability, safety)

Particle Loss and Attrition



Particle loss of 10^{-5} kg/kg for $1/kg is tolerable without significantly affecting the LCOE

Larger values of particle loss (10^{-4} kg/kg) are tolerable at reduced cost of particle (< $1/kg)

Conclusions

Developed a dedicated particle CSP technoeconomic tool capable of capturing interdependence of operating conditions, component geometry, and heat transfer media properties

Path to achieving LCOE cost targets identified for particle CSP systems

LCOE was found to minimize at conditions that do not maximize power cycle thermal efficiency

LCOE targets are unlikely to be achieved for particle cost above \$1/kg

Low absorptivity particles (~0.2) can achieve cost targets with no-cost particles

Particle loss/attrition needs to be below 10^{-5} for system to achieve cost targets

Future Work:

- Working with ANU to integrate the detailed particle component models into SolarTherm/Modelica

Acknowledgements

This work was funded in part or whole by the U.S. Department of Energy Solar Energy Technologies Office under Award Number 34211.

- Technology Managers: Matthew Bauer, Vijay Rajgopal, Shane Powers

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U.S. Department Of Energy

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